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The Impact of Shorter Product Life Cycles on Inventory Mismatch Costs: A Newsvendor Model

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ABSTRACT

The shortening of product life cycles has been an evident trend over time. As such, businesses' operation strategies underwent changes, yet little focus has been given to its effect on inventory management. A such, this research has the purpose of creating a mathematical tool to assess the impact on inventory mismatch costs as the cycles shorten, and its consequences on profits. For that, a Newsvendor Model is built, which is applied to a 3 and 2-period cycle. The findings describe the impacts measured, followed by conclusions. This research is finalized by the model's limitations and indications for future research.

Keywords

Product Life Cycle, Inventory Management, Mismatch Costs, Newsvendor Model

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1. INTRODUCTION

Social changes lead to an increase of consumer individualism and it can be observed in present times that it results in increased expectations and demand for a new product, (Moon 2005). To cope with this, organizations have been responding with constant innovation and new product introduction to remain competitive in their respective markets. As a result, it has become imperative for all businesses to restructure their strategies to capture additional value, reshaping in this way the time horizons of product life cycles.

Due to the frequency increase of new product launches or updated versions into markets, product variety has increased substantially. Consequently, product complexity management has become a tough challenge for entities to handle, combined with the resulting side-effect of product life cycles becoming shorter. Product life cycles with smaller time horizons create impact which is felt across the whole of value chains. As a result, supply chain operations are forced to accelerate, requiring levels of agility and responsiveness to increase as well.

Inventory management is deeply affected by this increasing trend, as new challenges arise when pursuing efficiency levels to remain high. New capacity and demand forecasts must be calculated according to the latest product release. Failing to accurately predict these will result in high mismatch costs that will impact operating profits. As a result, management faces the demanding task of ensuring additional value capturing when a new product enters the market.

This work project has the purpose of quantifying the impact created by shorter product life cycles on inventory mismatch costs, namely understock and overstock costs. The end goal is to, subsequently, measure the effect of mismatch costs on overall profits. This will be achieved by the construction of a unique Newsvendor Model, focusing on the components of time and capacity. Firstly, the research will present a literature review which will assess previously performed research on this topic, followed by a contextualization of key aspects that will be discussed in this paper. Then, the research question will be presented. Subsequently, the methodology chosen to conduct this work will be carefully explained. This consists of a detailed explanation of the created Newsvendor Model, including its specific nuances. Afterward, this model will be tested by assuming dummy variables, which its outcomes will be stated in the Findings and Discussion Chapter. Finally, this research will be finalized by presenting the obtained conclusions from this research, followed by limitations of the model and proposals for future research.

2. LITERATURE REVIEW

Most academic literature agrees that product life cycles have been shortening over time amongst distinct industries. Iwaarden (2006) recognizes this as an important current business climate trend that will continue to be present in the nearby future. More precisely, studies reveal how product life cycles have decreased by approximately 25% over the last 15 years, (Roland Berger 2013). Although some research focuses on this occurrence's impact on the operational division, it lacks focus on the direct impact on inventory management costs.

Inventory management has been a much-researched topic over the years, focusing particularly on the optimization of this procedure. For example, Augustine & Agu (2013) explain how effective inventory management is vital to ensure the success and growth of organizations. In fact, research has proven that a positive relationship exists between the efficiency of this practise with the firm's overall profitability, (Spin & Ennis & Spurlin 2015).

Profitability is a concept that receives a lot of emphasis on management and stakeholders. This happens since it indicates that an organization is operating in such a way that more money is entering than leaving the firm, (Spin & Ennis & Spurlin 2015). Also, Gill & Bigger & Muther (2010) state how the management of working capital is of high importance as it directly impacts the profitability of firms.

Demand volatility directly impacts inventory management costs as it is impossible to generate a perfect demand forecast. Thus, the uncertainty of demand is directly linked with mismatch costs and therefore, also impacts profitability. A significant amount of research has been conducted on this relationship through the newsvendor problem, given that this is a classical problem of inventory management literature, (Qin et al. 2011). A Newsvendor Model is an inventory control model that builds a relationship between demand volatility and its associated inventory mismatch costs (Arikan 2011).

Therefore, the purpose of this work project is to create a bridge between the already performed research regarding shorter product life cycle horizons and connect it with inventory mismatch costs. Being said that, this study differs from previous research by focusing on the financial impact caused on overall profits with the particularity of comparing results over different periods and capacity levels.

3. CONTEXTUALIZATION

A product life cycle can be used as an instrument of competitive power, (Levitt 1965). It is a methodical progress manager of a product's offering along a bell-shaped curve. This curve represents the stages of introduction, growth, maturity, and decline, which eventually leads to the product's removal from the market. This is used as the main tool for the decision-making process regarding marketing and positioning strategies, (Moon 2005). The practise of Product Life Cycle Management consists of controlling the life span of a given product and the information associated with it. If the product life cycle is managed efficiently, it will enable organizations to gain competitiveness and succeed at competing in global markets, (Saakvuory & Immonen 2005).

The latest trend shows that product life cycles have been shortening over the years, which has been evident throughout distinctive industries. Within the automotive sector, in developed countries, the average life of a car model has shortened from 8 to 4 years over the last decade, (Saadka & Molnár & Fedorko 2019). The FMCG business is another example, as they have been leading at reducing life cycle times within the processing industry, (Roland Berger 2012).

Shortening time horizons of product life cycles have several consequences, especially within the operational division of organizations. To start with, having shorter time frames forces the whole supply chain to flow at an accelerated rate. As a result, supply chains must be sufficiently agile to respond to these changes and have the ability to deal with increased levels of complexity, (Iwaarden 2006). Finally, capacity levels also suffer alterations. Due to the product variety increase, product versions get outdated much faster. Hence, when an organization is planning the introduction of a new type, it already foresees another update in the future. This leads to the total planned capacity over the product's lifetime to be reduced. Thus, businesses know that with the shorter and more frequent life cycles, they have less time to sell their inventory and convert it into revenues.

Augustine & Agu (2013) define inventory as either raw material, work-in-progress, consumables, or finished goods. Inventory often represents 40% of the total capital of industrial entities, (Moore & Lee & Taylor 2003). Also, in numerous cases, it represents 33% of company assets and 90% of working capital, approximately, (Sawaya & Giauque 1986). Hence, cost-effective management of inventory is highly desirable as it will positively impact profitability and growth. This has led to the adoption of new practises to optimize inventory management. Some of these practises, in the business world, including lean production strategies, supply chain management concepts, and optimized inventory movement, (Spin & Ennis & Spurlin 2015).

Effective management of inventory includes assuring an as accurate as possible forecast of demand. The variability of demand is caused by external factors to the organization, including economic indicators, political developments, or public relation hits, (Stobierski 2018). The challenge is thus to forecast an accurate future demand to match the units produced with the units sold. The difficulty lies within the long lead time that occurs between deciding on order quantities and when final market demand happens, (Department of Commerce U.S. 2018). The result of not being able to match production quantities with actual demand is a mismatch cost. There are two different types of mismatch costs: Overstock and Understock costs. An overstock cost, occurs when produced quantities are larger than actual demand. This forces the company to sell the leftover inventory stock at a discounted price. This discount will often lead to products being sold at a price below unit cost. The overstock represents the loss the firm will incur in each unit sold. On the other hand, a shortage of inventory can result in a lost sale when the actual demand exceeds the produced units. If more quantities had been produced, they would have been sold, therefore the company incurs an understock cost. To achieve maximum profits, quantities produced must match actual demand leading to mismatch costs being reduced to zero.

4. RESEARCH QUESTIONS

Defining a clear and specific research question is an imperative first step of any research project, (Eisenhardt 1989). By outlining the research question, it enables the author to verify the requirements and thus, the significance of the topic. It is essential for the question to be clear, focused, feasible, connected to already previously performed research. Then, the research project can move on to a secondary stage. This includes the decision-making on the methodology based on the selected research question, (Ritchie & Lewis 2013).

The literature emphasises how the trend of increasing product complexity and shortening product life cycles are here to stay. Therefore, it is relevant to understand the impact that these factors will have on operating costs, particularly on inventory management. Said that, this work project will answer the following research question:

"Do shorter product life cycles impact mismatch costs and profits negatively?"

5. METHODOLOGY

The methodology chosen to conduct the analysis that answers the research question is through the usage of a Newsvendor Model, a quantitative tool. As cited by Benzion et al. (2008): “In the newsvendor problem, the decision-maker, facing uncertain demand distribution, has to decide how many units to buy each day”. Therefore, a unique Newsvendor will be built, including distinctive assumptions relevant to this study. The objective of this model is to compare two different product lifecycles of an identical product. The only difference between the lifecycles is their time frames, given that one will have a sequence of 3-periods while the other only 2. The final goal is to analyse and reach conclusions on how inventory levels change as lifecycle horizons are shortened and how the company’s profits get affected by it.

5.1 Model Description

The model will be built considering the following situation. A company is launching a new product for which it is known that the product life cycle will be of 3 periods. The company is currently situated in period 0, right before the product gets launched in the market. Decision-making on quantities must happen at the beginning of each period, before knowing the actual demand that will take place. For example, at the beginning of period 1, the producer decides on the quantity he will put in the market for the whole of period 1. Then, demand will happen throughout the period. At the end of period 1, the producer can account for the sales that indeed happened and consider those results for the decision of the following period. This decision-making process is repeated for periods 2 and 3.

In this model, demand and produced quantities have the following characteristics: decision on produced quantities can be controlled by the company whereas demand cannot. Demand is volatile, meaning that its outcome depends on chance. For every period, it has two possible outcomes, either demand is high, *D(H)*, or demand is low, *D(L*). ***D(H)* is always double of *D(L)***, thus, $\mathbf{H = 2L}$. The quantities produced by the company for every period can also have two results. Either the produced quantity is high, *Q(H),* which matches the volume of *D(H),* or the produced quantity is low, *Q(L),* meaning that it matches the volume of *D(L).* Therefore, ***Q(H)* is also double of *Q(L)***. As a result, there are four possible combinations when considering one single period, Appendix 1. To finalize, quantities *H* and *L* are static, meaning that they do not change along the product life cycle.

The first combination is *D(H)* with *Q(H).* In this situation, the volume of produced quantities and demand are equal, meaning that all units produced will be sold and profits are maximized. The second combination is *D(L)* and *Q(L).* In this case, we have once again a volume match. Units produced and demand are equivalent, meaning that all units are sold and therefore, profits are maximized. The third combination is *D(H)* and *Q(L)*. If this outcome takes place, there will be excess demand for the units that were produced. Even though all the produced units will be sold, a *lost sale* will take place. The *lost sale* represents the lost opportunity of selling more units if they had been produced., which translates to an understock cost. The last combination possible is whenever *D(L)* and *Q(H)* happens. In this case, the quantities produced by the product exceed the demand for it. Not all units will be sold and as a result, the company incurs an overstock cost. Leftover stock is calculated as follows:

$$\begin{Bmatrix} 0 & , Q < D \\ Q(H) - D(L) & , Q > D \end{Bmatrix}$$

When looking only into the demand outcomes, *D(H)* or *D(L),* and recalling that a total of 3 periods exists, 8 possible demand combinations can occur throughout the lifecycle. These consist of the following: HHH; HHL; HLH; HLL; LHH; LHL; LLH; LLL. Hence, the goal of this model is to find the optimal decision-making path which maximizes the outcome given these 8 possible demand sequence possibilities.

Each demand outcome has a specific probability of occurring in each period. The probability of *D(H)* happening is β, while the probability of *D(L)* happening is $(1 - \beta)$. The occurrence of demand is independent and random, being thus not influenced by its outcome in the previous period.

Furthermore, the price at which each unit is sold in the market is p, and its associated COGS is c. Therefore, $(p - c)$ equals to the product's profit margin. The product´s salvage value is defined by v. As cited by AccountingTools (2019), the "salvage value is the estimated resale value of an asset at the end of its useful life". The salvage value in this model represents the resale value of a product when the quantities produced have exceeded total demand. For example, if a quantity *Q(H)* is produced and demand *D(L)* occurs, the company has the ability to sell quantities $(Q(H) - Q(L))$ on sale for the salvage value. Hence, this variable will used to calculate profits whenever overstock costs are present. The salvage value will always assume a value below the cost of goods sold. The calculation of $(c - v)$ represents the loss when units are sold at sale price.

Moreover, the variables p, c, and v do not change throughout the product life cycles. Their values are set at the beginning of period 1 and are fixed for the rest of the cycle. Therefore, the model assumes that p does not change along with the market conditions. Also, c remains unchanged as no learning effects are considered. On top of that, since no economies of scale present in this model, c is the same for both *Q(H)* and *Q(L)*.

Given that this model considers a multiple period horizon, the following assumptions hold regarding leftover stock. Whenever quantities are produced to exceed the demand and, therefore, the stock is leftover at the end of the period, it can be held and passed on to the subsequent period. As a result, it can be sold in the following period at the original market price if there is a demand for it, instead of at sale price (the salvage value). This action of holding the quantities in stock does not result in any additional costs for the company. The objective of holding stock is to increase the chance of encountering a high demand period in which the inventory surplus can be sold. Thus, this action can be repeated except in the last period of the lifecycle. Since no subsequent period exists in which the leftover stock can be sold. In the last period of the lifecycle, if the company has leftover stock, it must be sold on sale for the salvage value.

5.2 Decision Making Criteria

The chosen method to map the possible outcomes is through the implementation of a ramification problem. This is the most appropriate method given that uncertain events are the core of a Newsvendor Model. Designing a ramification problem allows the creation of a framework that formalizes action scenarios. Even so, it assumes that action specifications are not presumed to entirely describe all possible effects. Hence, this framework allows conclusions to be drawn regarding dynamic environments through the formal specification of the effects that are caused by a particular action, (Thielscher 1997).

Given that a ramification problem is to be used to design the Newsvendor Model, an adequate framework must be applied to study the model with logic and coherency. The following techniques are essential to better decide in the presence of uncertain events: (i) ensure the alternatives are well defined, (ii) quantify critical uncertainties, and (iii) highlight the objectives clearly, (Greenwood & White 2006).

To start with, ramifications are used to build a decision tree in order for all the alternatives to be mapped out. In this step, a chronology is of the highest importance given that in this model inventory gets accumulated over time. Hence, even though demand is random and not dependent on previous periods, profit calculations do get affected due to changes in inventory levels as time goes by. Furthermore, for every decision on quantities in each period, the decision tree will have two ramifications indicating what the subsequent demand possibilities are that can occur. This will be elaborated and mapped out from period 1 until period 3.

Afterward, the critical uncertainties are quantified. The outcome of demand is the only uncertain variable of this model. Hence, the demand outcome branches will either be populated by β or (1- β), according to *D(H)* or *D(L)*. Quantifying the uncertainties is crucial given that the probability of a certain demand happening will influence the company's decision on quantities. This happens given that the expected outcome is calculated through a weighted average of the probabilities.

Finally, the objectives of the decision-maker must be clearly stated. In this specific model, it includes the factors which are considered by the company when deciding on the quantities to produce before the demand is known. This model will incorporate two classical Newsvendor Model objectives indicated by Lau (1980): (i) maximization of decision-makers' expected profit utility and (ii) maximization of the probability of obtaining a certain level of profit. In sum, this company is entirely focused on obtaining the highest outcome possible and is thus risk-neutral. As such, it will decide on the quantities produced which will maximize profit in every period of the model regardless of emotional, behavioural, or external factors.

5.3 Quantifying the Model

To start with, a generic one single period Newsvendor Model will be introduced to understand its functioning. Figure 1 summarizes its outcomes.

		Demand	
		D(L)	*D(H)*
Quantity	*Q(L)*	*(p-c)*D(L)*	*(p-c)*D(L)*
	Q(H)	*(p-c)*D(L)-(c-v)*[(D(H)-D(L)]*	*(p-c)*D(H)*
	Probability	*(1-β)*	*β*

Figure 1: Outcome Matrix Single Period Model

If the producer opts to produce *Q(L),* the profit will be certain, and equal to: $(p-c)*D(L)$

If the producer opts for *Q(H),* the expected profit will be:

$$\{(p-c)*D(L)-(c-v)*\big(D(H)-D(L)\big)\}*(1-\beta)+(p-c)*D(H)*\beta$$

$$(p-c)*D(L)*(1-\beta)-(c-v)*\big(D(H)-D(L)\big)*(1-\beta)+(p-c)*D(L)*\beta$$
$$+(p-c)*\big(D(H)-D(L)\big)*\beta$$

$$(p-c)*D(L)+\{(p-c)*\beta-(c-v)-(1-\beta)\}*((D(H)-D(L))$$

As such, the producer prefers to opt for *Q(H)* whenever:

$$\{(p-c)*\beta-(c-v)-(1-\beta)\}*((D(H)-D(L))>0$$

After manipulating the formulas above, the following relationship is found:

$$(1-\beta)>\frac{p-c}{p-v}\rightarrow Q(L)$$

$$(1-\beta)<\frac{p-c}{p-v}\rightarrow Q(H)$$

Hence, for a single period Newsvendor model, the decision on Q which will optimize the outcome will depend on which condition above is met.

Now, the three-period Newsvendor Model will be introduced, which deals with a sequence of periods instead of one. Due to this change in nature, the three-period model will suffer some modifications when compared to the one above, Figure 2.

T1			
		Demand	
		D(L)	*D(H)*
Quantity	*Q(L)*	*(p-c)*D(L)*	*(p-c)*D(L)*
	Q(H)	*(p-c)*D(L)*	*(p-c)*D(H)*
	Probability	*(1-β)*	β

Figure 2: Outcome Matrix Period 1

In period 1 (T1), if the producer opts for *Q(L),* its profits will be certain and equal to $(p-c)*D(L)$. On the other hand, if the producer opts for *Q(H),* the expected profit will be $(p-c)*D(L)+(p-c)*(D(H)-D(L))*\beta$. Given that the expected profit of *Q(H)* is larger than the profit of Q(L), the producer will always opt to decide on *Q(H)* in period 1. The reason for the expected profit of the decision *Q(H)* to be higher is due to a subsequent period existing to this one. If the worst scenario were to happen, meaning that *D(L)* would occur, leftover units would be able to be passed on to the following period without any additional cost. This way, no overstocking would happen in period 1.

After the decision on Q, the demand for period 1 will occur. If *D(H)* happens, the model is in equilibrium given that the produced quantities equal sold quantities, $D(H) = Q(H)$. Thus, profit will be $(p - c) * D(H)$ and there will be no leftover inventory at the end of the period. Contrary, if *D(L)* occurs, produced quantities exceed demand which results in leftover stock at the end of the period. As such, profits will be $(p - c) * D(L)$ and leftover stock equals $Q(H) - Q(L) = Q(L)$ since $H = 2L$.

In period 2 (T2), the decision on quantities will be based on the level of demand that occurred in period 1. As such, there will be two situations to consider: *D(H)* in period 1 or *D(L)* in period 1. Starting with *D(H)* in period 1, the model in this situation is in equilibrium, meaning there is no leftover inventory at the end of the cycle. This creates a situation identical to the one encountered at the beginning of period 1. For this reason, the decision-making for period 2 is the same as in period 1. As such, the outcome matrix and expected profit calculations are equivalent to the ones presented above (Figure 2).

On the other hand, if period 1 had *D(L)*, the company will have passed on the leftover stock created by the mismatch of demand and quantities produced. Hence, inventory at the beginning of period 2 will be *Q(L).* Given this, if the company would decide to produce *Q(L)* in period 2, the final quantity held would be *Q(H)*, $(Q(L) + Q(L) = Q(H))$. If the company instead would decide to produce *Q(H)*, he would put in the market an irrational quantity of product. The quantity would equal $Q(L) + Q(H) > D(H)$, meaning the company would offer product quantities above the maximum possible demand.

Therefore, the model will now assume that the company has the ability to produce 0 quantities of product in periods 2 and 3. Even though the producer has now the possibility of not producing in these periods, the quantities he will put in the market remain unchanged, either *Q(H)* or *Q(L).* The only adjustments are the quantities produced, which are now either 0, *Q(H),* or *Q(L),* depending on the situation. The option of not producing will only be worthwhile if the producer finds himself with accumulated stock from a previous period. Given that the maximum leftover stock that can be passed on to the next period is $Q(L) = Q(H) - Q(L)$, the procedure will in this case always want to produce either 0 or *Q(L).* In sum, in the presence of leftover inventory level *L*, the producer will produce *Q(L)* if he wants to bring *Q(H)* to the market or produce 0 when wanting to bring *Q(L)* into the market. In the presence of no leftover inventory, the company will produce either *Q(L)* or *Q(H)*, bringing *Q(L)* or *Q(H)* to the market.

Now, retreating back to the scenario of *D(L)* happening in period 1, the producer will find himself with an accumulated stock level *L* at the beginning of period 2. As such, the decision on produced quantities will be either 0 or *Q(L).* This will allow him to bring *Q(L)* or *Q(H)* to the market, respectively. Figure 3 summarizes the outcome possibilities.

T2			
		Demand	
Q Produced	Q Offered	*D(L)*	*D(H)*
0	*Q(L)*	*(p-c)*D(L)*	*(p-c)*D(L)*
Q(L)	*Q(H)*	*(p-c)*D(L)*	*(p-c)*D(H)*
	Probability	*(1-β)*	β

Figure 3: Outcome Matrix Period 2

If the producer opts to not produce and put in the market *Q(L)*, profits will be certain and equal to $(p - c) * D(L)$. On the other hand, if the producer opts to produce *Q(L)* and put in the market Q(H), the expected profit will equal $(p - c) * D(L) + (p - c) * (D(H) - D(L)) * \beta$. Once again, the expected profit of putting in the market *Q(H)* out wages the profit of *Q(L).* The reason for this is because there exists a subsequent period that allows you to pass on leftover inventory when quantities exceed demand. Passing on inventory *Q(L)* from period 2 to period 3 will have no consequences, once again. Because in the presence of leftover inventory level *L*, the producer will produce *Q(L)* if he wants to bring *Q(H)* to the market or produce 0 when wanting to bring *Q(L)* into the market. Hence, in period 2, the producer will always want to opt to bring to the market *Q(H).*

After deciding on Q, demand will take place during period 2. If *D(H)* will happen, the model will be in equilibrium. All units put into the market are sold, resulting in no leftover inventory at the end of the period. Expected profits will equal $(p - c) * D(L) + (p - c) * (D(H) - D(L)) * \beta$. On the other hand, if *D(L)* happens, the producer will reach the end of the period with a leftover inventory level of $Q(H) - Q(L) = Q(L)$. This will be passed on to period 3 without negative consequences for the company, as previously explained. In this case, profits will be certain and equal $(p - c) * D(L)$.

In period 3, the model finds itself in the last period of the cycle. As such, no subsequent period exists, meaning that leftover stock can no longer be held to the next period. The company must decide to either put *Q(H)* or *Q(L)* in the market. Said that, it can be concluded that period 3 of this product life cycle is identical to a single period newsvendor model. Hence, as defined previously, the decision on Q will be determined according to which condition is met:

$$(1 - \beta) > \frac{p - c}{p - v} \rightarrow Q(L) \; or \; (1 - \beta) < \frac{p - c}{p - v} \rightarrow Q(H)$$

As a result, two possible scenarios can occur in period 3, producing *Q(H)* or *Q(L),* as summarized in Figure 4 below. If the first condition is met, the producer will opt to put *Q(L)* in the market for the last period of the life cycle. If at the beginning of the period there would be an inventory level of L available, no production will occur. If no stock is present at the beginning of the period, *Q(L)* will be produced. This will yield a profit of $(p - c) * D(L)$.

If the second condition is met, the optimal decision is for the producer to put *Q(H)* in the market. In this case, it will always produce either *Q(L)* or *Q(H)*, producing 0 is not an option. If the inventory level is equal to L at the beginning of the period, it will only produce *Q(L)* as $Q(L) + Q(L) = Q(H)$. If the inventory level is 0 at the start of the period, it will have to produce Q(H). This quantity decision will result in the expected profits of $(p - c) * D(L) + (p - c) * (D(H) - D(L)) * \beta$.

T3			
		Demand	
Q Produced	Q Offered	*D(L)*	*D(H)*
0	*Q(L)*	*(p-c)*D(L)*	*(p-c)*D(L)*
Q(L)	*Q(H)*	*(p-c)*D(L)-(c-v)*[D(H)-D(L)]*	*(p-c)*D(H)*
	Probability	*(1-β)*	β

Figure 4: Outcome Matrixes Period 3

To summarize, it is possible to conclude from this 3-period model that the optimal decision-making path is to produce $Q(H) - Q(H) - Q(H)/Q(L)$ for period 1,2 and 3, respectively. Only the period 3 decision is dependent on which values the variables assume.

After studying the newsvendor for the 3-period lifecycle product, this analysis will be repeated assuming the lifecycle got shortened to 2 periods. The consequences of this action and its caused modifications to the model will be resumed in the following chapter.

6. FINDINGS AND DISCUSSION

6.1 Three Period Model

As previously discussed, 8 possible demand combinations can occur throughout the 3-period model. From the methodology previously used, it was possible to conclude that two optimal paths can maximize the producer's outcome depending on those 8 combinations, either $Q(H) - Q(H) - Q(L)$ or $Q(H) - Q(H) - Q(H)$.

This research will now assume one of the conditions is met in order to test the solution found above. This will be achieved by assigning dummy values to the model's variables and verify if the same conclusion can be drawn. For this example, the following condition will hold:

$$(1 - \beta) > \frac{p - c}{p - v}$$

The model's variables will assume the following values:

$$Q(H) = D(H) = 2000 \;\; Q(L) = D(L) = 1000 \;\;\; p = 8 \;\;\; c = 6 \;\;\; v = 3 \;\;\; \beta = 0.5$$

$$(1 - \beta) > \frac{p - c}{p - v} = \; (1 - 0.5) > \frac{8 - 6}{8 - 3} = 0.5 > 0.4$$

Given these values, one can conclude that the company's optimal decision is to offer $Q(H) - Q(H) - Q(L)$ in periods 1, 2, and 3, respectively. Therefore, this example verifies the conclusions found in the methodology above. Now, to quantify the impact of this decision, a table will be constructed to summarize the effect on the company's profits according to all 8 possible demand outcomes, Figure 5.

v=3 Demand Outcomes	Q(H) Produced T1	Q(H) Produced T2	Q(L) Produced T3	Leftover stock	OC	Profit w/o OC	Total Profit
Low - Low - Low	2000	1000	0	0	0	6000	6000
Low - Low - High	2000	1000	0	0	0	6000	6000
Low - High - Low	2000	1000	1000	0	0	8000	8000
Low - High - High	2000	1000	1000	0	0	8000	8000
High - Low - Low	2000	2000	0	0	0	8000	8000
High - Low - High	2000	2000	0	0	0	8000	8000
High - High - Low	2000	2000	1000	0	0	10000	10000
High - High - High	2000	2000	1000	0	0	10000	10000
Average							64000

Figure 5: Three Period Model Q(H)-Q(H)-Q(L)

It should be recalled that not producing is an option, leading to produced quantities and quantities put in the market sometimes differ. As such, the quantities shown at the top of the table for all 3 periods indicate the quantities put into the market, *Q(H)* or *Q(L).* The Produced columns indicate the actual produced quantities by the company in every single period, either 2000, 1000 or, 0. T1, T2, and T3 represent period 1, period 2, and period 3, respectively. The Inventory Left will always be 0 or 1000, hence, 0 or *Q(L). Q(L)* is the maximum leftover stock level at the end of the cycle which happens when the combination *D(L)* and *Q(H)* occurs in the last period. Then, the Overstock Cost (OC) indicates the cost the producer underwent by having overstock present at the end of the cycle. This is calculated by multiplying the margin $(c - v) = (6 - 3) = 3$ by the leftover stock quantities at the end of the cycle. The Profit Without Overstock refers to the value yield from the units sold throughout the whole cycle. This is obtained by multiplying the profit margin, $(p - c) = (8 - 6) = 2$, by the number of units sold according to the specific period. Finally, the Total Profit column is the result of subtracting Overstock Costs from Profit Without Overstock.

In order to clarify the calculations of Figure 5, this study will carefully explain a demand outcome scenario, for example, $D(L) - D(L) - D(L)$. This outcome means demand will equal 1000 units in all three periods while quantities put to market are $2000 - 2000 - 1000$. As such, in period 1, the producer will produce and put into the market 2000 units. During period 1 *D(L)* occurs, meaning that only 1000 are sold. Therefore, the company will have a leftover inventory of 1000 ($2000 - 1000 = 1000$) that will be passed on to period 2. In period 2, the company will put in the market 2000, hence, it will only need to produce 1000. Then, *D(L)* occurs again, meaning that he will sell 1000 and have 1000 leftover stock to pass on to period 3. Finally, in period 3, the company will put 1000 in the market. Thus, the company will sell the leftover stock and produce 0, leading to leftover inventory to be 0 at the end of the cycle. Profit Without Overstock will equal $(2000 + 1000 + 0) * (8 - 6) = 6000$ and Overstock Costs $(6 - 3) * 0 = 0$. Therefore, the total profit will equal to $6000 - 0 = 6000$.

From these findings, this research was able to conclude the following. A low salvage value translates into a large $(c - v)$ margin, as a result, it represents a large risk for the company when offering *Q(H)* in the last period of the model. As seen in the example above, the salvage value is only half of the production unit cost. This would mean that at the end of the life cycle if stock is leftover, there would be a significant loss when selling at the sale price. Thus, the larger the margin $(c - v)$, the lower the revenues of selling the leftover stock at a discount, meaning mismatch costs will be higher and therefore profits lower. Hence, in this example, the company will always offer *Q(L)* in the last period of the cycle to lower its risk.

6.2 Two Period Model

For the analysis of the 2-period model, consider the following hypothetical situation. The same company is planning to launch the same product on the market. During this initial phase, the company receives the news that the product´s life cycle has been miscalculated and that in fact, it only has a duration of 2 periods instead of 3.

With only two available periods, this model becomes a less complex version of the 3-period model. The methodology used for the 2-period model is very similar to the one used for the 3-period model, Appendix 2. The only difference is that in a model of 3 periods there are 2 periods where the company can accumulate stock. These are periods 1 and 2, which can pass on the stock to the subsequent periods 2 and 3, respectively. However, in a 2-period model, the company can only accumulate stock in period 1 and pass it on to period 2. As such, the optimal decision quantity of this new model will be of *Q(H)* in period 1 since this is a period where the company can accumulate stock, similarly to periods 1 and 2 of a 3-period model. The decision on quantities for period 2, the final period, will be the same as the one in period 3 of a 3-period model, following the condition or the single-period model. As such, the optimal decision depends on:

$$(1-\beta) > \frac{p-c}{p-v} \rightarrow Q(L) \ or \ (1-\beta) < \frac{p-c}{p-v} \rightarrow Q(H)$$

In sum, from the methodology of the 2-period model, it can be concluded that the company optimizes its outcome by putting in the market either $Q(H) - Q(L)$ or $Q(H) - Q(H)$.

In order to test the above methodology of the 2-period model, the same assessment will be performed as done in chapter 6.1. As such, the same dummy values will be used in the 2-period model's variables, assuming the same condition holds. Before doing so, it should be recalled that given that this model only considers two periods, the possible demand outcomes throughout the cycle will now be 4 instead of 8. These outcomes are: $LL; LH; HL; HH.$ Given the dummy values, the following holds:

$$H = 2000 \quad L = 1000 \quad p = 8 \quad c = 6 \quad v = 3 \quad \beta = 0.5 \quad (1-\beta) = 0.5$$

$$(1-\beta) > \frac{p-c}{p-v} = (1-0.5) > \frac{8-6}{8-3} = 0.5 > 0.4$$

This example confirms once again the conclusion found in the methodology. Given this condition, the company's optimal decision-making path is to offer in the market $Q(H) - Q(L)$

in period 1 and 2, respectively. Likewise, in the analysis of the findings of the 3-period model, a table will be constructed to summarize the findings of the 2-period model given the 4 demand

v=3	Q(H)	Q(L)				
Demand Outcomes	Produced T1	Produced T2	Leftover stock	OC	Profit w/o OC	Total Profit
Low - Low	2000	0	0	0	4000	4000
Low - High	2000	0	0	0	4000	4000
High - Low	2000	1000	0	0	6000	6000
High - High	2000	1000	0	0	6000	6000
Total	2000					20000

outcome combinations, Figure 6. All calculations were performed identically to above.

Figure 6: Two Period Model Q(H)-Q(L)

Once again, an example of demand combination will be explained step-by-step, in particular, $D(H) - D(L)$. This outcome means demand as well as quantities put in the market equal $2000 - 1000$. In this scenario, the company wants to offer in the market *Q(H)* in period 1 and will therefore produce and put in the market 2000 units. Then, *D(H)* takes place in period 1, causing all the produced units to be sold. As a result, no leftover stock will be passed on, meaning the inventory level will be 0 at the beginning of period 2. At the start of period 2, the company will produce 1000 units as it wants to offer *Q(L)* in the market. Then, *D(L)* occurs in period 2, meaning that once again all inventory produced will be sold, resulting in leftover stock 0 at the end of the cycle. This also means that OC will be 0. Profits without OC will be $(2000 + 1000) * (8 - 6) = 6000$. Total Profit will be $6000 - 0 = 6000$.

In the 2-period model, the same conclusion can be drawn regarding the salvage value and the unit production cost. The larger the margin of $(c - v)$, the riskier it is for the company to bring *Q(H)* to the market in the last period. Therefore, when v=3, the company optimizes by putting *Q(L)* in the market in period 2. In this way, it reduces the chance of leftover stock to be present in the cycle, which would result in low revenues from the units sold at the sale price. As a consequence of choosing *Q(L),* mismatch costs will be lower than if *Q(H)* would be put into the market, but so will the total profits. Hence, there is a trade-off, the more the company wants to reduce risk, the more expected profit it must forgo.

6.3 Average Profit per Period

Now, the impact of shortening the product's life cycle from 3 to 2 periods will be measured. Since the two models have different time frames, it would not be coherent to compare the accumulated profits throughout the cycle. In order to overcome this situation, the **Average** Profit per Period will be calculated. For this, the Total Profit values for each demand outcome must be converted to per period. Hence, for the 3-period model, total profits are divided by 3. For the 2-period model, total profits are divided by 2.

This leads to the following results, in the 3-period model, the Average Profit per Period is 2667. In the 2-period model, the Average Profit per Period is 2500, as shown in Figure 7. Given that $2500 < 2667$, one can conclude that as the product life cycle shorten, so do profits. In this case, the profit decrease was approximately $6.26\% = (2500 - 2667)/2667$.

v=3 Demand Outcomes	Total Profit	Total Profit p/ Period
Low - Low - Low	6000	2000
Low - Low - High	6000	2000
Low - High - Low	8000	2667
Low - High - High	8000	2667
High - Low - Low	8000	2667
High - Low - High	8000	2667
High - High - Low	10000	3333
High - High - High	10000	3333
Total	64000	2667

v=3 Demand Outcomes	Total Profit	Total Profit p/ Period
Low - Low	4000	2000
Low - High	4000	2000
High - Low	6000	3000
High - High	6000	3000
Total	20000	2500

Figure 7: Average Profit Per Period

The above-described finding makes it possible to answer the research question of this study. It is indeed confirmed that shortening product life cycles impact negatively the company's overall profits. This can be justified due to the fact that smaller time frames mean that fewer periods are available to sell the product. As a result, when leftover stock is created, there is a smaller chance of encountering a future period where demand allows for the product to be sold at market price. This will lead to higher levels of leftover stock to be present at the end of the cycle, meaning that mismatch costs will be higher and, therefore, reduce average profits.

7. CONCLUSION

The current study tries to fill the existing literature gap between shorter product life cycles and their impact on inventory mismatch costs. Several studies have been conducted on understanding the reason behind the trend of shortening product life cycles, and the quantification of it. Although previous research has focused on measuring the impact shorter cycles cause on the operational department of companies, little focus has been given to the inventory division. Therefore, this study aims to assess the impact of shorter product life cycles on inventory and evaluate its effect on profits.

To assess that, it was necessary to fully understand the dynamics of product life cycles and their timeframes. Also, an in-depth study was conducted in order to comprehend the practise of inventory management and how its effective management contributes to companies' profits.

A quantitative method was chosen to conduct the proposed topic of the study and the main research question. This was done through the creation of a unique Newsvendor Model, a mathematical tool. Its objective was to allow for mismatch costs to be quantified in an environment in which uncertain demand prevails while decision-making on produced quantities must be made. This model was applied to two different product life cycles. One consisting of three periods and the second of only two. Both life cycles correspond to an identical product.

Three important findings were able to be concluded in this study. Firstly, it was verified that the shortening of the product life cycle impacts average profits negatively, which confirmed the research question. We can confirm that shorter time frames create more leftover inventory at the end of the product's life cycle, causing higher mismatch costs, which negatively impact the company's profits. This results from smaller time horizons reducing the chance of selling leftover inventory created in periods where demand is low. This means the company has less chance of encountering periods with high demand where the stock created can be sold. In sum, businesses will be faced with less time to convert their inventory into revenues.

The second significant finding is regarding the unit production cost and its salvage value. A smaller salvage value translates into a larger margin between *c* and *v*, resulting in a higher risk for the company to produce high quantities in the last period of the product life cycle. Hence, the smaller the salvage value, the lower the revenues made from discount sales if demand low occurs in the last period of the product life cycle.

Finally, the last finding of this study concludes that holding inventory to the next period instead of selling it at sale price has a positive impact on profits. By holding the inventory to the next period, once again, the chance of encountering a high demand period increases. This reduces mismatch costs in the final period due to less inventory to be present at the end of the product life cycle.

In terms of managerial applicability, this model serves as a tool to quantify inventory mismatch costs throughout the product's life cycles. Additionally, it enables companies to evaluate the impact on profits when the product life cycle is shortened, particularly when it relates to inventory management and mismatches between demand and quantities launched.

8. LIMITATIONS AND FURTHER RESEARCH

Models are imprecise given that they are only an approximation of a natural phenomenon, (Quay & Frangos 2016). Said that, this Newsvendor Model is no exception to it. The first limitation identified is the fact that this research was entirely theoretically conducted. This means the conclusions drawn can lack accuracy since mathematical descriptions of the model are imperfect. On top of that, the model requires all assumptions to be met. If this is not the case, the model cannot be implemented, and no conclusions can be drawn. Both factors decrease the reliability level of this model.

The second limitation is that this model assumes that inventory holding costs do not exist. In practise, this is most likely not the case. Inventory takes up physical space which translates into an additional cost for the company. In case of needing to hold a larger inventory level, either storage capacity must be expanded, or an additional warehouse must be rented. If this model were to include this variable, overstock costs would have been quantified higher which would then impact profits and possibly the decision making. Hence, this Newsvendor Model's accuracy as a mathematical tool is reduced given the low accuracy of this assumption.

The third limitation relates to the fact that both demand outcome and decision on quantities can only take two possible results. In a real business environment, this is most likely not the case given that there will be many more possibilities available. As a result, deciding on quantities would be much more complex. Once again, the model's accuracy is reduced given the low accuracy of this assumption.

Future studies could focus on applying this model to existing businesses across varying industries and assess whether this model shows more accuracy in a particular kind of industry. Firstly, the effect of the type of stock could be evaluated. Secondly, a sensitivity analysis could be performed for the variables price, unit cost, and salvage value. In this way, it could be assessed which change in variable would most impact the decision making. Finally, it could be studied how the average life cycle horizon of the industries impact the conclusions.

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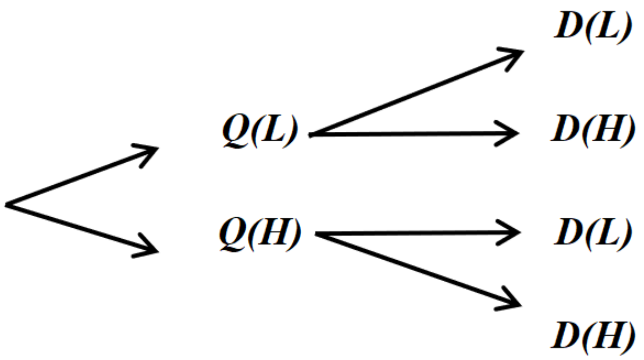
APPENDICES

Appendix 1: Single Period Outcome Ramification



Appendix 2: Two Period Model Methodology

T1			
		Demand	
		$D(L)$	$D(H)$
Quantity	$Q(L)$	$(p-c)*D(L)$	$(p-c)*D(L)$
	$Q(H)$	$(p-c)*D(L)$	$(p-c)*D(H)$
	Probability	$(1-\beta)$	β

T2			
		Demand	
Q Produced	Q Offered	$D(L)$	$D(H)$
0	$Q(L)$	$(p-c)*D(L)$	$(p-c)*D(L)$
$Q(L)$	$Q(H)$	$(p-c)*D(L)-(c-v)*[D(H)-D(L)]$	$(p-c)*D(H)$
	Probability	$(1-\beta)$	β